Coherent and neutral pion production results from MINERνA

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Abstract. MINERνA is a neutrino-nucleus scattering experiment employing multiple nuclear targets. The experiment is studying neutral pion production due to coherent, resonant and deep-inelastic processes, from both charged current and neutral current reactions. Neutral pions are detected through their two photon decay and the resultant electromagnetic showers. We will describe the analysis for the cross sections of inclusive and exclusive processes.

Keywords: Neutrino, cross sections, neutral pion

CHARGED CURRENT NEUTRAL PION PRODUCTION

We are interested in reconstructing $\bar{\nu}$ events where the signature of a two photon decay from a π^0 is present, and one reconstructed μ^+ was found in both the MINERνA detector[1] and MINOS near detector[2][1]. Figure 1 shows the event topology of interest: two electromagnetic showers separated from the event vertex[2] and one long track due to the μ^+.

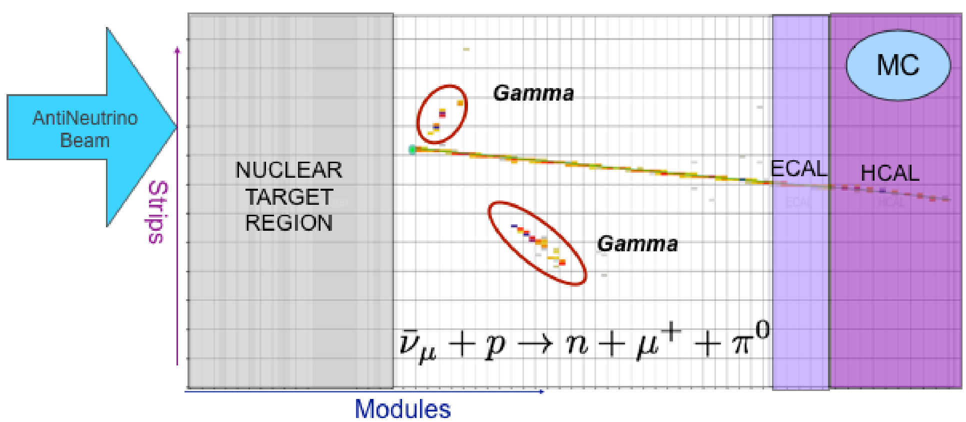

FIGURE 1. A candidate event for a π^0 decay in the active region. The nuclear targets are upstream of the active region and calorimeters to contain additional particles coming from the neutrino interaction are downstream of the active region.

Event Selection

Final-state interactions (FSI) are the key to define our different samples (CCπ^0 inclusive and CCπ^0 exclusive). Considering we are selecting anti-neutrinos events, our main signal or sample is dominated when the final state

[1] MINOS near detector contains magnets to complete the muon reconstruction
[2] The muon vertex defines the event vertex

particles are 1 μ^+ and 1 π^0. In order to reconstruct π^0 events in the MINERνA detector, we apply the following selections:

- One muon track matched to a track in Minos (to select μ^+)
- Hits to be used in the reconstruction must be within 25ns of the vertex time.
- The muon vertex must be inside the fiducial volume.
- The energy in the upstream nuclear target region is less than 20 MeV.
- Showers must be reconstructed by a Hough Transform (energetic showers) or an Angle Scan (low energy showers).
- Two EM showers with a the shower vertex separated from the muon vertex.
- Invariant Mass between 70 - 200 MeV/c^2 for CCπ^0 inclusive and Invariant Mass between 4 - 240 MeV/c^{2}for CCπ^0 exclusive.
- Vertex Energy less than 13 MeV for CCπ^0 exclusive events.

We divided our signal in two types: those with a μ^+, π^0 and any other particle(s) as final state particles (CCπ^0 inclusive) and those where there are only three final state particles μ^+, π^0 and neutron (CCπ^0 exclusive).

Invariant Mass

The invariant mass must be approximately equal to the π^0 mass (134.9 MeV/c^2). If the invariant mass is not close to the π^0 mass the electromagnetic showers may not have resulted from a π^0 decay, or we may have an incorrect combination of gammas.

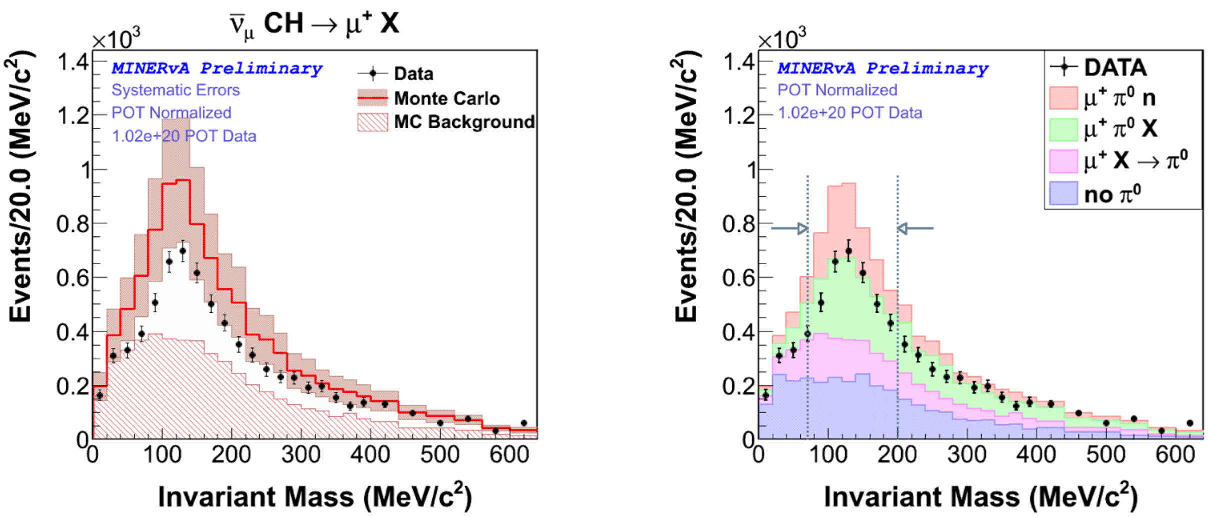

FIGURE 2. Left: Invariant mass data and Monte Carlo comparisons. Right: CCπ^0 inclusive contains events with $\mu^+ n \pi^0$ (pink) and $\mu^+\pi^0$X (green) in the final state. The selected events must be between the dotted lines.

CCπ^0 Inclusive and CCπ^0 Exclusive

To reconstruct CCπ^0 inclusive events, we select events in the mass range (70 - 200 MeV/c^2). Background events could be pion charge exchange in the detector or incorrect reconstruction. We find a purity of 54% and an efficiency of about 4.2%. Figure 2 shows invariant mass distribution for these events.

The vertex energy is the energy contained within a radius of 90 mm from the center in the event vertex. The event vertex is well defined by the upstream position of the μ^+ trajectory. This variable provides strong evidence of extra activity coming from the $\bar{\nu}$-interaction. This variable is important for reducing the background for CCπ^0 production.

To reconstruct CCπ^0 exclusive events, we select events with a vertex energy less than 13 MeV[3] andinvariant mass between 40 - 240 MeV/c^2. With these cuts we achieve an efficiency of 7% with purity of 67% for CCπ^0 exclusive events. Figure 3 shows the invariant mass distribution for these events.

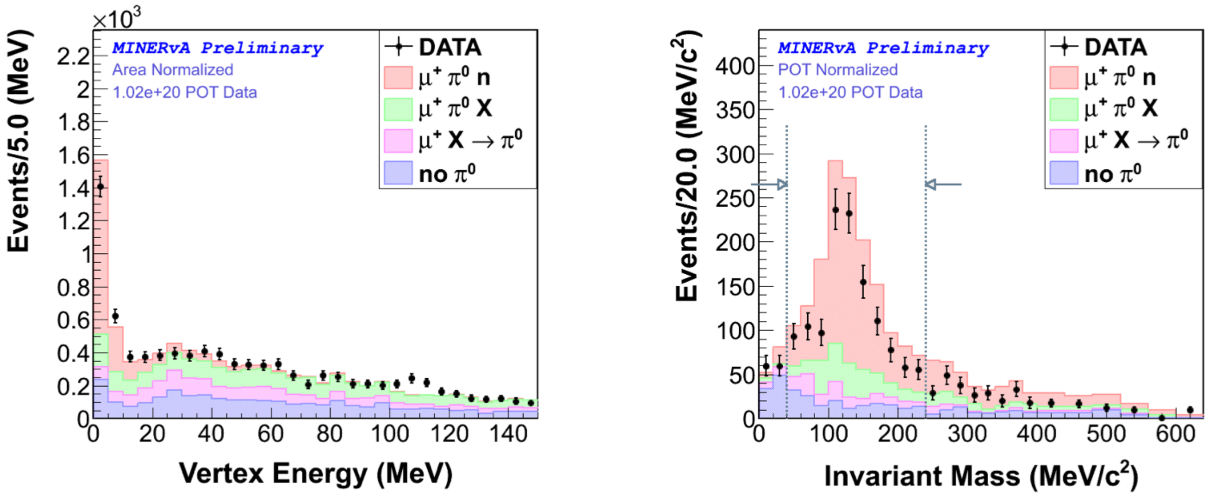

FIGURE 3. Left: Vertex energy including our categories for data and Monte Carlo comparisons, cut was made at 13 MeV to separate CCπ^0 exclusive from CCπ^0 inclusive. Right: Invariant mass stack histograms including our different categories. CCπ^0 exclusive contains events with $\mu^+\pi^0$n (pink) in the final state. The selected events must be between the dotted lines

Cross Section

The reconstruction of the observable cross sections for CCπ^0 inclusive and CCπ^0 exclusive samples was done in several steps.

- Background subtraction: our reconstructed sample is contaminated by non-signal events (background) and does not fully contain all signal events.
- Unfolding: the reconstructed variables usually deviate from their true value. We need to take account of this effect by "unfolding" the signal events.
- Efficiency correction: the efficiency is used to recover the signal event rate from the reconstructed candidates.

Having a comprehensive CCπ^0 event reconstruction allows for detailed preliminary measurements of CCπ^0 interaction cross-sections. These cross sections (Figs. 4 and 5) are important for the understanding of the π^0 production in neutrino interactions. We still need to improve our understanding of the errors resulting from the uncertainty in the flux and the systematic errors resulting from the π^0 reconstruction.

CC COHERENT PION PRODUCTION

The defining feature of this interaction is that the hadronic final state contains a single pion and a residual nucleus in its ground state. Coherent interactions are a significant background in neutrino oscillation experiments because the NC coherent pion production can mimic ν_e appearance.

The cross sections are small and backgrounds (usually from resonance pion production processes) are large. Measurements have been made for CC coherent, however recent measurements[3] and [4] could not find evidence for coherent production at the very lowest energies. NC coherent has only been estimated from the sum of signal plus background.

[3] 13 MeV was chosen from MC studies of CCπ^0 exclusive final states.

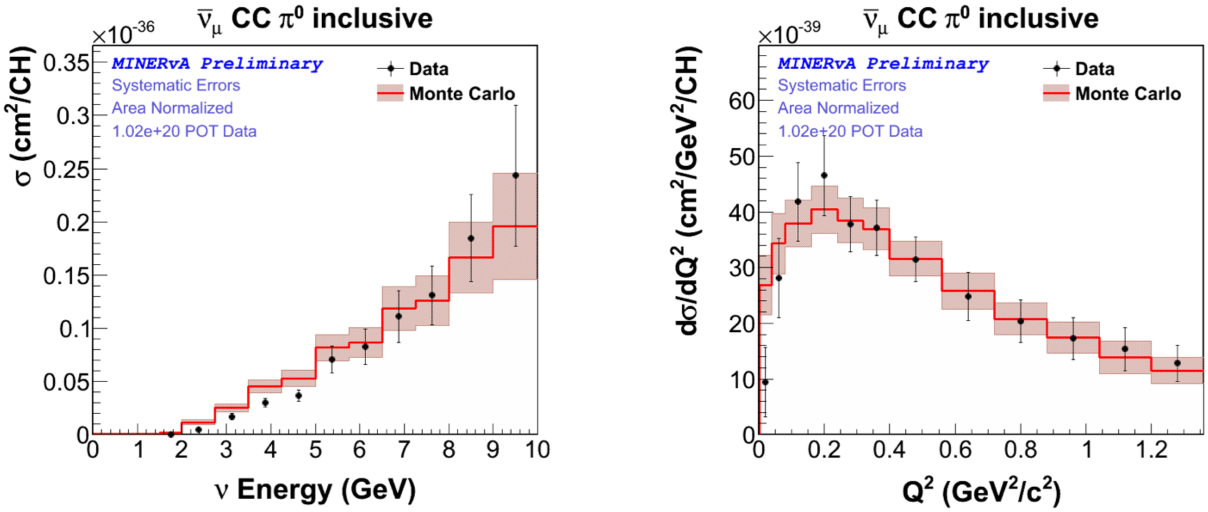

FIGURE 4. Left: Total observable cross-section as a function of neutrino energy for CCπ^0 inclusive reaction. Right: CCπ^0 inclusive differential cross section as a function of Q^2.

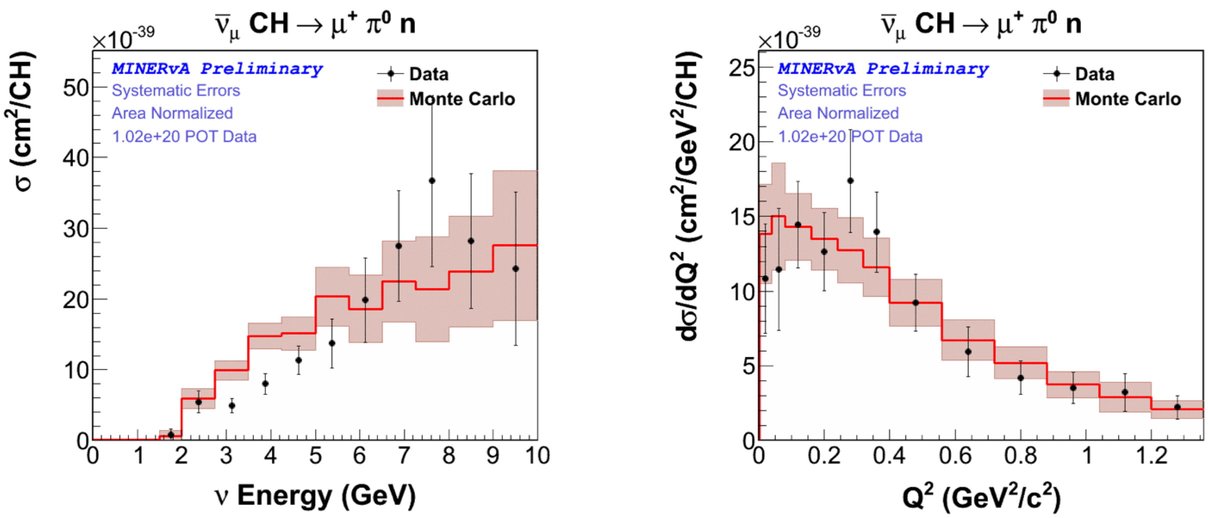

FIGURE 5. Left: The total observable cross-section as a function of neutrino energy for CCπ^0 exclusive. Right: CCπ^0 exclusive differential cross section as a function of Q^2.

Towards a Data-Driven Analysis

CC coherent pion production should be produced at very low Q^2 ($Q^2 < m_\pi^2$). MINERvA takes that assumption as a starting point in its effort to isolate CC coherent pion production. In this analysis we require two tracks with a common vertex in the tracker region, with one of them identified as a muon using the MINOS near detector. By cutting $Q^2 < 0.2$ (GeV/c)^2 Figure 6 (left) MINERvA has enriched the CC coherent candidates, the evidence of this can be seen in the energy around the vertex, which is the visible energy within 200mm from the interaction vertex Figure 6 (right).

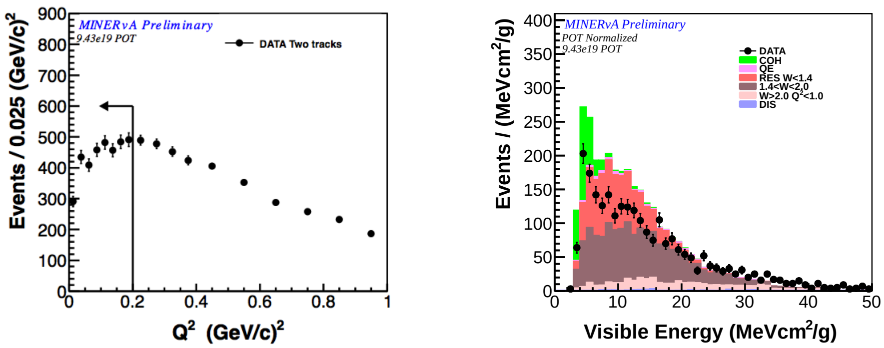

FIGURE 6. Left: Q^2 Distribution for two tracks events. Right: Vertex visible energy for event with $Q^2 < 0.2$ GeV^2

CONCLUSIONS

- MINERνA has the capability to study π^0 production for both neutrino and anti-neutrino reactions and isolate exclusive processes using the energy around vertex. NCπ^0 production is a large background for neutrino oscillation experiments.
- MINERνA is able to isolate CC coherent candidates by using the event kinematics.
- With high statistics and good tracking capabilities MINERνA will provide a precision measurement of the coherent pion production cross section on multiple nuclear targets.
- The algorithm to isolate, reconstruct and identify electromagnetic showers works for π^0 identification. Preliminary results show good identification.

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